**Upper Animas Watershed**

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Preliminary Assessment - PASI Sites - PA/SI Watershed - Water Quality and Sources of Metal Loading to the Upper Animas River Basin

# WATER QUALITY AND SOURCES
# OF METAL LOADING TO THE UPPER ANIMAS RIVER BASIN


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The hydrograph for the 1992 water year for the Animas River below Mineral Creek, A-72, Figure 2, illustrates several features important to water quality. Snowmelt, beginning in late April or early May and lasting through July, produces the most runoff. Thunderstorms, common during the late summer and early fall may produce occasional floods. Although discharge rates for these storms may be high they have shorter durations. The low flow period lasts from November through April. Gage records for the 1992 and 1993 water years indicate that peak runoff from Cement Creek precedes the upper Animas River and Mineral Creek by about two weeks. The concentration inorganic constituents in most of the streams of the basin is least during periods of high flow and highest during low flow thus the temporal streamflow pattern is important to water quality.

Bankfull, mean annual and 3-year low flow statistics are shown in Table 2. The bankfull flow, defined as the instantaneous peak discharge that has a recurrence of 1.5 years on average, determines the capacity of the active channel (Leopold, 1994). This flow is approximated by the one-day high flow . The mean annual discharge is the sum of daily flows divided by the period of record. Snowmelt usually produces the bankfull flow in the Upper Animas, even though record floods have been caused by rainfall. Most sediment is transported between the mean annual and the bankfull flows. Streamflows higher than the bankfull flow are rare, have short durations, and do not have a major influence on the chemistry of the water. These events, however are important mechanisms for moving mine waste deposited on low terraces adjacent to the flood plain. Mine waste remains on terraces above the bankfull stage at several locations in the Animas Canyon and at other sites within the basin providing evidence of former major floods that have occurred in the area.

The frequency and duration of particular streamflow levels determines the length of time aquatic organisms are likely to be exposed to a concentration of a pollutant. Colorado's approach for regulatory purposes assumes that dilution based on low flow values will be available. Acute criteria use the 1-day duration low flow and chronic criteria use the 30-day duration low flow. The recurrence frequency for both is once in three years on average. The acute and chronic low flows are defined as the 1-E-3 and 30-E-3 flows, respectively.

The flow-duration curve for the Animas River below Mineral Creek, Figure 3, shows the percentage of time a particular flow level is equaled or exceeded. The scale of the X-axis is in normal probability units in order to better represent extreme or rare flow events. The median flow (half of the days greater and half

Table 2. Selected flow statistics for upper Animas watersheds, adjusted to the gage at Howardsville for the 1965-1982 period of record

| | Annual 1-day high cfs | Mean annual cfs | 1-E-3 cfs | 30-E-3 cfs |
|---|---|---|---|---|
| Animas River at Howardsville | 818 | 102 | 10 | 10 |
| Animas River at Silverton (A-68) | 1040 | 112 | 14 | 14 |
| Cement Creek (CC-48) | 274 | 35 | 8 | 8 |
| Mineral Creek (M-34) | 856 | 97 | 14 | 15 |
| Animas River bl Mineral Creek (A-72) | 2210 | 260 | 41 | 42 |

of the days smaller) of 100 cubic feet per second is less than the mean annual flow (269 cfs). The mean annual flow on the duration curve is exceeded on only about 25 percent of the days because most of the runoff occurs in a short time period, May through July. The long tail on the right side of the duration curve shows that there is relatively small absolute differences between the annual low flow and extreme low flow events.

## Stream Chemistry

**Significant chemical weathering is occurring in the Animas, Cement, and Mineral Creek watersheds as evidenced by the total dissolved solids (TDS) concentrations, Table 3. The data in Table 3 are indicative of base flow conditions. Nearby Vallecito Creek, outside the Caldera, had a TDS concentration of 48 mg/l for the same time period. Cement Creek has the highest TDS followed by Mineral Creek and the Animas River, respectively. Cement Creek contributes 20 percent of the flow to A-72, but it accounts for 45 percent of the dissolved solids.**

**Calcium, silica, and magnesium, are the principal cations in all three streams. Sulfate is the predominate anion. Carbonate and bicarbonate, as indicated by the low alkalinity, are virtually absent in Mineral and Cement Creeks. Alkalinity and hardness have similar levels in most stream water in Colorado. Calcium and magnesium quantities indicates that all three streams have hard water, however low alkalinity means the hardness is almost entirely noncarbonate. Water hardness is known to ameliorate metal toxicity for some metals, and this factor is figured in to Colorado's calculation of water quality standards (CDPHE, 1986). Other studies have suggested that in waters of low alkalinity and high hardness that standards should be calculated based on**

alkalinity (CDPHE, 1986). Cement Creek and Mineral Creek have high hardness and no alkalinity. The Animas River has relatively high hardness and low alkalinity. Because of this disparity between hardness and alkalinity, it is possible that water quality standards calculated on the basis of hardness may not represent the toxic effects of water in the basin to aquatic life.

The amount of sulfate is a direct indicator of the quantity of metal-sulfide minerals being oxidized. All three streams have high levels of sulfate. The sulfate concentration in Cement Creek is about four times higher than in the Animas River, and like TDS accounts for 45 to 50 percent of the sulfate measured at A-72. By way of comparison the sulfate concentration in nearby Vallecito Creek in November 1993 was 8 mg/l.

High levels of iron, accompany high sulfate levels in Cement and Mineral Creeks. Iron occurs in the dissolved ferrous (Fe++) state and the colloidal ferric (Fe+++) state. Colloidal iron settles, forming the yellowish or reddish stain seen on the rocks of the stream channel of Cement and Mineral Creeks. It also appears seasonally on the Animas River from Cement Creek to downstream of Elk Creek. Concentrations of dissolved iron in well oxygenated surface waters in Colorado exceeding 0.100 mg/l are unusual except in areas affected by acid mine drainage. Parkhurst (1993), hypothesized that settlable iron from Cement and Mineral Creeks is partially responsible for inhibited aquatic life in the lower reaches of the Animas River. Iron from the Animas above Silverton is minor.

Another measure of weathering of metal-sulfide minerals and acid mine drainage is pH. Dissolution of pyrite ($FeS_2$) is the main cause of stream acidity. Aquatic life may suffer slight adverse impacts at pH's less than 6.0, however the main impact of low pH is increased solubility of metals controlled by pH (Thurston, et al, 1979). Most streams in Colorado are slightly basic, having an average pH between 7.6 and 8.0. The pH in Cement and Mineral Creeks, both less than 5, indicate acid conditions. The pH in the Animas, however is only slightly less than the pH of 7.8 observed in Vallecito Creek.

Cement Creek and Mineral Creek have uniquely high concentrations of dissolved aluminum compared to other Colorado streams. Aluminum is an abundant element, but is insoluble at pH's found in most natural waters. Aluminum shows both conservative and nonconservative behavior in acidified stream waters. At pH less than 4.5 it is mostly dissolved (conservative), but reacts to form insoluble salts at pH's greater than 5.0 (Nordstrom and Ball, 1986). The whitish coatings found on the rocks in portions of all three stream channels are precipitated salts of aluminum.

Table 3. Composition of Major Ions (total) in the Animas, Cement, and Mineral Creek Watersheds--November 1993

| | Concentration in milligrams per liter | | |
|---|---|---|---|
| Analyte | Animas (A-68) | Cement (CC-48) | Mineral (M-34) |
| pH s.u. | 7.1 | 4.0 | 4.6 |
| Alkalinity | 23 | 0 | <5 |
| Ca | 173 | 607 | 250 |
| K | 0.83 | 1.6 | 0.94 |
| Mg | 3.3 | 9.1 | 7.2 |
| Na | 3.0 | 5.5 | 4.2 |
| Si | 9 | 29 | 20 |
| Cl | 2.5 | 2.5 | 2.5 |
| F | 0.5 | 1.8 | 0.5 |
| NO3-N | 0.25 | 0.25 | 0.25 |
| P | 0.03 | 0.03 | 0.03 |
| SO4 | 150 | 683 | 277 |
| Al | 0.025 | 5.133 | 3.500 |
| Cd | 0.002 | 0.002 | 0.002 |
| Cu | 0.002 | 0.033 | 0.030 |
| Fe | 0.085 | 7.800 | 5.267 |
| Mn | 1.133 | 2.433 | 0.570 |
| Pb | 0.002 | 0.016 | 0.004 |
| Zn | 0.653 | 0.723 | 0.417 |
| TDS | 344 | 1356 | 572 |
| TSS | 5 | 21 | 19 |

The level of zinc in all three streams is toxic to all species of trout except for brook trout. Cadmium, copper, and lead levels in Cement Creek and Mineral Creek are toxic to most forms of aquatic life at ambient hardness. Other metals toxic to aquatic life associated with mining regions include chromium, silver, and nickel, however these metals do not appear in the dissolved state in streams in the upper Animas River Basin.

Dissolved lead in Cement Creek exceeds the actions level for lead under the Safe Drinking Water Act. Levels of iron, sulfate, and pH in Cement and Mineral Creeks do not meet water quality criteria for domestic water supplies. Manganese exceeds recommended criteria in all three streams. Neither of these streams are used as a water source for public entities in San Juan County. Private use of the water for domestic purposes is unknown.

tributaries of the West Fork, and Burrows Gulch, a tributary of the North Fork, contain in-active mines and mills and have high levels of metals.

The pH of the Animas River, 5.7 is least at Animas Forks, increasing to 7.4 at A-28 just above Eureka Gulch. The pH in the mainstem remains above 6.5 to Silverton, A-68, Figure 6. This pH level contributes to the formation of insoluble aluminum and copper, lead, and iron, but is not high enough to appreciably affect dissolved cadmium, manganese or zinc.

Cinnamon Creek, Grouse Gulch, Picayne Gulch, Minnie Gulch, Maggie Gulch, Cunningham Creek, and Boulder Creek, which enter the Animas River between Animas Forks and Silverton, have very low metal concentrations, thus diluting the levels of cadmium, manganese, and zinc. Measurable sources of zinc within this reach include Eureka Gulch and Burns Gulch. Several small draining mines and tributaries between Maggie Gulch and Silverton were sampled. Although they contain metals, their impact is small.

Eureka Gulch, A-34, is a source of zinc. One important source is water exiting the Terry Tunnel, near the head of Eureka Gulch. SGC treated this discharge during snow free months, but the site is not accessible for treatment in the winter so it could be an even larger source during the snow cover months. SGC sealed the Terry Tunnel in the summer of 1996. Future monitoring at A-34 and at A-68 will help to determine the effect of this source on zinc levels in the Animas River.

The zinc concentration, Figure 7, shows a general decrease between A-14 and A-68, however there is a small increase between Eureka Gulch, A-28 and Minnie Gulch, A-40. This includes the old townsite of Eureka where milling operations were conducted during the early part of the century. Mill tailings spread across the valley remain from these historic operations, and may be a source of zinc to the Animas during periods of snowmelt or heavy rains.

Cadmium and zinc are the only metals to exceed Colorado's aquatic life criteria in the Animas River at Silverton. The cadmium concentration, at 1.7 ug/l, is slightly elevated above aquatic life criteria, but the zinc concentration, 540 ug/l, is exceeds aquatic life criterion for all species of trout except brook trout.

## Cement Creek

The Cement Creek watershed contains the main entrance to the Sunnyside Mine at Gladstone. This mine is one of Colorado's largest gold mines, containing over sixty miles of underground workings. Before it closed in 1991, the mine produced lead, copper, zinc, and silver along with gold. Ore from the mine was trucked from the portal of the American Tunnel at Gladstone, located near the confluence of Cement Creek and South Cement Creek, to the Mayflower Mill northeast of Silverton. Through an agreement with the CDPHE, signed in May 1996, two bulkhead seals will be placed in the American Tunnel and the mine will fill with water. The valve on the first seal was closed in late 1996.

The discharge from the American Tunnel, prior to sealing, averaged about 3.5 cfs and contained about 15 mg/l of zinc. SGC treats the discharge, removing virtually all of the zinc. After the second seal is placed, no discharge from the tunnel is expected.

Cement Creek from its headwaters above Gladstone, Figure 8, to Silverton has dissolved aluminum, cadmium, copper, iron, lead, manganese, and zinc concentrations that are acutely and chronically toxic to most forms of aquatic life. The pH of Cement Creek, in contrast to the Animas River, rarely exceeded 5.0 anywhere in the basin, including the mainstem, Figure 9. Stream pH's less than 3.0 were measured in Prospect Gulch (CC-24), North Cement Creek (CC-06) and Ohio Gulch (CC-40). The lower pH means that a larger percentage of the metals will be dissolved. Low pH water throughout the watershed indicates oxidation of metal-sulfide minerals, that have been attributed to both natural and mining related causes.

Cement Creek has high levels of iron and aluminum. Wright (1995) found natural springs in Topeka and Ohio Gulches with dissolved aluminum concentrations ranging up to 22,000 ug/l and dissolved iron concentrations ranging up to 78,000 ug/l. Other sources of iron include an iron bog that is adjacent to Cement Creek between Prospect Gulch and Minnesota Gulch, North Cement Creek, Prospect, Ohio, and Topeka Gulches. Except for North Cement Creek, the largest iron sources are downstream of the American Tunnel. Precipitated iron coats the substrate of Cement Creek, staining it red from the confluence with North Cement Creek to Silverton. Dissolved iron concentration at Silverton averaged 4100 ug/l.

High aluminum concentrations accompany high dissolved iron levels in Cement Creek. The aluminum is probably owing to acid conditions resulting from weathering of pyrite (Nordstrom, personal communication). Moreover, pH's below 5 in the mainstem retards aluminum precipitation. The aluminum profile for the mainstem, Figure 10, shows the highest average concentration at C-30, downstream of the iron bog. At Silverton, C-48, the concentration averaged 3,200 ug/l which greatly exceeds the aquatic life acute criterion of 750 ug/l.

Dissolved cadmium, copper, lead, and zinc in Cement Creek above the American Tunnel (C-05) averaged 12, 358, 8, and 2,575 ug/l, respectively for the four sampling periods. These levels are acutely and chronically toxic to most forms of aquatic life. The zinc concentration in the mainstem is relatively constant from Prospect Gulch to Silverton, Figure 12, averaging 890 ug/l at C-48. North Cement Creek has the highest concentrations of cadmium, copper, lead, and zinc. South Cement Creek and Prospect Gulch also have high concentrations of cadmium, copper, lead, and zinc. SGC's removal of a large waste dump, located near the confluence of South Cement Creek and Cement Creek, to their main tailings pond north of Silverton between 1992 and 1995, may have affected the metals results. Treatment at the American Tunnel provides adds carbonate, temporarily increasing alkalinity that reduces the concentration of dissolved copper at C-21, Figure 11.

Mineral Creek

Mineral Creek begins on Red Mountain Pass and near the rim of the Silverton Caldera. Red Mountain ore bodies are associated with pipes that possibly filled with hot acid waters that ate away at the surrounding rock, later filling metal-laden minerals (Blair, 1996). The Koehler and Longfellow, whose adits are about 100 yards apart, are located in this area. Metal concentrations in Mineral Creek below Red Mountain Pass were among the highest found in the Upper Animas Basin. Dissolved aluminum, cadmium, copper, lead, and zinc concentrations averaged 5,545, 52, 4,815, 9.5, and 15,300 ug/l, respectively in Mineral Creek above Chatanooga, M-04, Figure 13. Carbon Lakes (M-03) and Browns Gulch (M-12) drainages, south of Red Mountain Pass contribute some cadmium, copper, iron, and zinc. Mine wastes are found in both watersheds. Mill Creek and Porphry Gulch, both of which are west of the caldera have low metal concentrations, and provide significant dilution upstream of the Middle Fork.

The Middle Fork, the second largest tributary to Mineral Creek, has high dissolved aluminum and iron concentrations. Aluminum and iron concentrations at M-22 near the mouth averaged 3,225 ug/l and 9,900 ug/l, respectively. The Paradise, Ruby Trust and Bonner mines are in the Middle Fork, however aluminum and iron concentrations from these mines account for only part of the high concentrations at M22. Additions of aluminum and iron from the Middle Fork affect Mineral Creek all the way to Silverton.

South Mineral Creek, the largest tributary to Mineral Creek, adds some zinc. Bear Creek another large tributary is free from metals. Drainage from the North Star Mine adit just outside of Silverton contributes zinc to Mineral Creek. Although dilution decreases the concentration of cadmium and zinc from M-4, to the gage near Silverton, these metals remain at concentrations that are toxic to aquatic life. Figure 14 shows the change in zinc concentration from M-04 to Silverton, M-34.

The aluminum profile of Mineral Creek is shown in Figure 15. Although most of the aluminum and iron are precipitated before reaching the gage on Mineral Creek near Silverton, Mineral Creek is a major source of dissolved and particulate aluminum and iron to the Animas River.

The synoptic study identified two important groups of metals: 1) cadmium, copper, and zinc; and 2) aluminum and iron. The concentrations of dissolved lead and manganese are high in a few locations, however neither exceeded aquatic life criteria in segments proposed for the aquatic life classification. Cadmium, copper, and zinc have common sources within the watershed. The focus is on zinc owing to its generally conservative behavior in the basin, and because it requires the largest reduction to meet the water quality goals proposed for the Animas below Mineral Creek. It is expected that reducing zinc will achieve levels of cadmium and copper sufficient to meet aquatic life goals.

Aluminum and iron have many common sources in the Cement Creek and Mineral Creek watersheds. Although dissolved aluminum is toxic to aquatic life, it is present because of acid produced by the weathering of metal sulfide minerals. Remediating sources of iron will probably address the aluminum problem.

## AQUATIC LIFE

### Animas River

The abundance and diversity of aquatic life in the Animas River and its tributaries above Maggie Gulch are a reflection of the water chemistry. Electrofishing California Gulch, the Animas below Burrows Gulch, Eureka Gulch, and the Animas mainstem above Eureka Gulch found no fish in 1992. The mean relative abundance of macroinvertebrates was low, ranging from one organism to forty five organisms per square meter. Aquatic habitat on the mainstem between Eureka Gulch and Minnie Gulch is seriously degraded. The channel is braided and there is very little riparian vegetation owing to tailings washed onto the gravel terraces.

Electrofishing in 1992 found brook trout at several locations in the Animas River between Maggie Gulch and Cement Creek. Brook trout represented multiple age and size classes suggesting that they are self-reproducing. The mean relative abundance of macroinvertebrates ranged from 153 to 1305 organisms per square meter.

The Animas River between Cement Creek and Mineral Creek was not sampled, however, mass balance calculations indicate that dissolved aluminum, copper, and iron could significantly limit brook trout and the most tolerant species of macroinverebrates. The braided channel and sparse riparian vegetation indicates poor physical habitat, further limiting the ability of the segment to support aquatic life.

No fish were found in the Animas between Mineral Creek and A-72. A few brook trout were present at the lower end of the segment above Elk Creek (A-73). The mean relative abundance of macroinvertebrates ranged from 20 to 83 organisms per square meter at A-72 and A-73, respectively. The abundance and diversity of both fish and macroinvertebrates is lower in this segment than in the reach of the Animas between Maggie Gulch and Cement Creek. The habitat for both fish and macrobenthos is impaired by a reddish precipitate that coats the substrate of the Animas between Mineral Creek and Elk Creek. Water chemistry indicates that the quality is better than that required for brook trout and an evaluation of physical habitat, other than the embedded substrate indicates that habitat should not be limiting for aquatic life.

Electrofishing the Animas River canyon between Elk Creek and Tacoma by the CDOW produced both brook and rainbow trout above Cascade Creek in 1992. The mean relative abundance of macroinvertebrates was a rather low 23 organisms per square meter above Cascade Creek.

Cement Creek

Ambient concentrations of aluminum, cadmium, copper, manganese, and zinc in Cement Creek preclude the ability of aquatic life to survive. Deposits of oxides of iron and aluminum on the channel substrate limits the ability of macroinvertebrates to survive. Electrofishing at two sites on Cement Creek in 1992 failed to produce any fish. Macroinvertebrate mean relative abundance per square meter was one organism.

## Mineral Creek

Mineral Creek above South Mineral Creek was electrofished at two locations in 1992. No fish were found. Macroinvertebrate mean relative abundance per square meter on the mainstem ranged from 1.5 to 3.5 organisms. Mean relative abundance per square meter was 133.5 organisms at the headwaters of the Middle Fork.

Electrofishing four sites in South Mineral Creek in 1992 found rainbow and brook trout. Production ranged from around 14 pounds per acre to nearly 85 pounds per acre in the headwaters.

Macroinvertebrate relative mean abundance per square meter ranged from 94.5 to 1725 organisms.

No fish were found in Mineral Creek between South Mineral and the Animas River. Macroinvertebrate mean relative abundance per square meter at one site was four organisms.

# METAL LOADING

Water quality goals have been established for iron and zinc in the Animas River below Mineral Creek. Sources of zinc are from the Animas River above Silverton, Cement Creek and Mineral Creek. Cement Creek and Mineral Creek are the sources of iron. Zinc and iron contributed from each watershed are weighted by the streamflow and the concentration of the analyte. The product of streamflow and concentration is the load. The greatest improvements to water quality will come from targeting areas that have the highest concentrations and significant discharges. Figure 16 shows the relative dissolved zinc load contributed to the Animas River below Mineral Creek from the three watersheds. Iron loads are discussed qualitatively because the data collected in the synoptic surveys lend themselves to simple mass balance methods that do not account for geochemical complexities associated with iron's reactivity, settling, and resuspension characteristics. Source areas for the zinc and iron loading within the three sub-basins is discussed below.

## Animas

Sources of zinc loading to the Animas River exceeding one kilogram per day for at least one sampling event are shown in Figure 17. The measured zinc load from these areas as a percentage of the zinc load measured in the Animas at Silverton averaged 61 percent, the least from any of the three watersheds. The West Fork of the Animas, which includes California and Placer Gulches, accounts for an average of 22 percent of the zinc load measured at A-68.

California Gulch contributed 46 percent of the zinc load measured in the West Fork, A-10, while Placer Gulch accounted for 37 percent. The remaining 17 percent comes from the West Fork. The largest area of loading in California Gulch is between sites A-18 and A-17, Figure 5. Two adjoining draining adits and associated waste dumps (sites A-17a and A-17b) appear to account for the loading (Herron, and others, 1995). In Placer Gulch the biggest increase in zinc loading was measured between sites A-22 and A-21, an area that includes a draining adit and associated waste dump at the Sunbank Mine. This adit was plugged in 1994, tailings were removed from the drainage, and small wetland treatment ponds were placed in 1996, thus the synoptic surveys do not reflect the recent work. The Columbus Mine and the Bagley Tunnel, above the confluence with the North Fork, also contribute zinc.

The North Fork, A-09, accounted for about 5 percent of the zinc load at A-68. Most of the load is from Burrows Gulch. Herron and others (1995) identified six draining adits and a waste rock pile upstream of this site.

Eureka Gulch averaged 15 percent of the load measured at A-68 during the period the synoptic surveys were done. The Terry Tunnel which drains to Eureka Gulch, as previously not is partially treated from early June through October, but is untreated during the winter. No winter estimates of zinc loading are available for Eureka Gulch, however it is likely that zinc loading from the Terry Tunnel and Eureka Gulch were under estimated for about half the year. It should also be noted that the Terry Tunnel was sealed in 1996.

The zinc load from Burns Gulch averaged 8 percent of the load at A-68. No mine sites were investigated in Burns Gulch.

The surface loads identified through the synoptic surveys in the reach between Eureka Gulch and Cement Creek are small. An adit above Minnie Gulch (A-41), an adit upstream of Cunningham Creek (A-46), Cunningham Creek, Arrastra Creek, and Boulder Creek all contribute small loads of zinc to the Animas. Collectively they are less than ten percent of the load measured at A-68.

The source of the remaining zinc load, about 40 percent has not been determined. The Animas River flows across a large deposit of glacial and alluvial gravels between Eureka Gulch and Howardsville. Mill tailings remaining from historic operations at several locations may be a source of the load.

## Cement Creek

Four general areas account for most of the zinc load in the Cement Creek. These areas, shown in Figure 8, are the mainstem above the American Tunnel including North Cement, South Cement Creek, and Prospect Gulch. The iron bog adjacent to Cement Creek between Prospect Gulch and Minnesota Gulch appears to be the fourth major contributor.

Nearly half of the zinc load during high flow (June and July) and roughly one-third during the September rain was measured at C-18 which is above the American Tunnel and includes North Cement. Figure 18 shows a lower percentage of the zinc load in Cement from North and South Cement Creek and Prospect Gulch during the baseflow period than during runoff and high flows. The iron bog appears to be the largest source of zinc during the base flow period, contributing 44 percent of the load during the October event. Although the dissolved zinc load measured during the synoptic surveys from the American Tunnel treatment plant is very low, total recoverable zinc reported in the SGC discharge monitoring reports suggests some particulate zinc is discharged. The large volume of effluent together with particulate zinc which is subject to dissolution because of low pH in Cement Creek produces the zinc load estimate shown in Figure 18.

The zinc load from the bog was estimated by the difference in flow and zinc concentration in Cement Creek upstream and downstream from the bog. Although this is a relatively coarse measure of the load from the bog, it appears to contribute substantial load to Cement Creek. The importance of the zinc load from the bog needs to be verified during subsequent studies.

Cement Creek produced the most iron load (total recoverable) of the three basins. The iron load in Cement Creek at Silverton ranged from a high of 1080 kg/day during the June event to a low of 322 kg/day during the October event. North Cement, South Cement, Prospect Gulch, and Ohio Gulch were the biggest sources during the June spring runoff event and the rainfall runoff sampling event of September 1991. These areas contributed relatively little iron load during the October low flow event.

the seasonal factor is great. The standard errors for zinc, following adjustment, are similar among the Animas, Cement and Mineral Creek. The seasonal component affecting metal concentrations has important implications. Changes in analyte levels owing to management practices or remediation projects will be more readily recognized if seasonal differences are accounted for in the analysis. Load reductions from a watershed during a flow or season may have a varying impact on the level of analyte at A-72.

MODELING

The highest zinc concentrations are measured in the Animas at the lowest flow. Moreover, Figure 3 shows that low flows predominate over the hydrologic year. Aquatic life water quality standards for zinc are higher for waters with high hardness and water hardness is greatest when the flow is low. The varying relationships among discharge, zinc concentration, and water hardness for the Animas, Cement, and Mineral Creeks were combined in order to evaluate their impacts on the Animas below Mineral and to estimate the zinc reduction required to meet criteria for varying types of aquatic life.

A mass balance water quality model was developed to estimate the zinc load reduction from the three upper watersheds that would be required to meet the zinc goal of 225 ug/l for the Animas River below Mineral Creek. It is a simple mixing model that distributes flow at A-72 among the A-68, C-48, and M-34 gages and calculates the expected zinc concentration at each gage as a function of discharge and season. Zinc is treated as a conservative constituent. Predictions of the dissolved zinc concentration resulting from various load reduction schemes in each of the three watersheds can be evaluated.

A reduction of nearly 70 percent in the zinc concentration from ambient levels is required at A-72 to provide protection for a full range of sensitive aquatic species. This calculation is based on flow and zinc concentrations observed at moderately low flow during the snowpack season (70 cfs and hardness equal to 240 mg/l). The resulting zinc value, 230 micrograms per liter, is similar to the goal standard of 225 ug/l proposed to the Colorado Water Quality Control Commission in 1994. During the snow free period a reduction of around 60 percent is required based on the mean annual discharge (269 cfs) and a corresponding hardness of 120 mg/l.

The relative contribution of zinc to the Animas below Mineral Creek from the upper Animas, Cement, and Mineral Creek watersheds in shown in Figure 16. Clearly zinc load reductions must come from all three watersheds if the zinc goal is to be met.

Areas contributing the greatest zinc loads are shown in Figures 17, 18, and 19. Potential remediation targets should focus on specific mine adits and waste dumps and the feasibility for reducing the zinc load from them within these areas. Additional characterization of the Animas and Cement Creek watersheds is needed because they contain areas of zinc loading that has not been attributed to a specific area. Achievable load reductions are subjective prior to site specific feasibility studies. It is mathematically possible to arrive at a large number of load reduction plans among the three tributaries, therefore the objective of feasibility analysis is to suggest a practical combination of load reduction alternatives, including technical, cost, political, and social considerations.

## Summary and Conclusions

Manganese and zinc are the metals that can be predicted with the most confidence. At observed pH's in the upper Animas, an average of 94 percent of the manganese and zinc are in the dissolved form. Other metals, including dissolved aluminum, copper, lead, and iron are highly dependent on pH and their concentrations cannot be reliably predicted from simple dilution methods.

No single basin or source can be treated which will achieve the 225 ug/l zinc goal proposed for the segment of the Animas below Mineral Creek. Zinc load reduction must come from multiple sources.

The Animas River above Eureka Gulch does not support aquatic life. Dilution from tributary streams and precipitation of most metals owing to higher pH of the water lowers the concentration of all metals. Downstream of Maggie Gulch, dissolved zinc is the only metal to exceed aquatic life criteria. Brook trout, which are tolerant to higher zinc concentrations than other trout species, and macrobenthos are found in the Animas River between Maggie Gulch and Cement Creek.

The Animas River above Silverton accounts for about 38 percent of the stream flow and 42 percent of the zinc load to A-72. Data provided by the Colorado River Watch program suggests there is a larger percentage of the zinc load from this area during the late winter-early spring period. The iron load from this part of the basin is relatively minor.

The largest surface sources of zinc loading above A-68 are California/Placer Gulches, Eureka Gulch, Burns Gulch, and the North Fork of the Animas, respectively. Numerous mine related sources containing significant zinc loads are found within these areas. The addition of zinc from tributaries to the Animas River between Maggie Gulch and Cement Creek is relatively minor. About 50 percent of the zinc load at A-68 could not be accounted for from surface sources. Infiltration and percolation of snowmelt and rainfall into mill tailings deposited in the alluvial gravel of the Animas River in the vicinity of Eureka and seasonally untreated discharge from the Terry Tunnel to Eureka Gulch may account for some of the load to the Animas River in this reach.

Cement Creek is a significant source of acidity, aluminum, cadmium, copper, lead, iron, manganese, and zinc in the Animas River basin. Cement Creek does not meet water quality criteria for aquatic life or drinking water. Cement Creek is completely without fish and is nearly devoid of macrobenthos.

Mixing the low pH water of Cement Creek with the higher pH water of the Animas precipitates most of the aluminum, copper, and lead prior to reaching A-72. Some of the iron is precipitated, however very little of the cadmium, manganese, or zinc is reactive at the ambient pH.

Cement Creek produces 13 to 19 percent of the streamflow to A-72 but accounts for 30 percent of the zinc load and over half of the iron load. Sources of iron include an iron bog, Prospect Gulch, and Ohio Gulch. Larger iron loads produced during high flow events suggest that the sources are from weathering of surficial material. Data collected for this study are insufficient to distinguish between natural and mine related sources of iron.

Most of the zinc originates upstream from Minnesota Gulch. Prospect Gulch, South Cement Creek, North Cement Creek, and the mainstem of Cement Creek above the North Fork are important areas. An iron bog adjacent to the Cement Creek mainstem between Prospect Gulch and Minnesota Gulch is an apparent large source of the zinc load. Treatment at the American Tunnel removes approximately 100 pounds of zinc per day that otherwise would flow down Cement Creek.

Mineral Creek has significant levels of aluminum, cadmium, copper, iron, and zinc that extends from near its source on Red Mountain Pass to the confluence with the Animas River near Silverton. Mineral Creek, is devoid of both fish and macrobenthos.

Mineral Creek contributes 36 percent of the streamflow and 22 percent of the zinc load to A-72. Nearly eighty percent of zinc loading in the Mineral Creek drainage is from the Red Mountain Pass area which includes the Koehler and Longfellow mines. A sizeable reduction in the zinc load from this area should have a quantifiable impact on the zinc concentration at A-72.

The Middle Fork of Mineral Creek is the largest single source of iron in the upper Animas Basin. Many iron bogs are visible in the Mineral Creek basin, but their contribution has not been quantified. Data collected for the synoptic surveys indicates that the iron load from the Mineral Creek basin exceeds the iron load from Cement Creek under low flow conditions.

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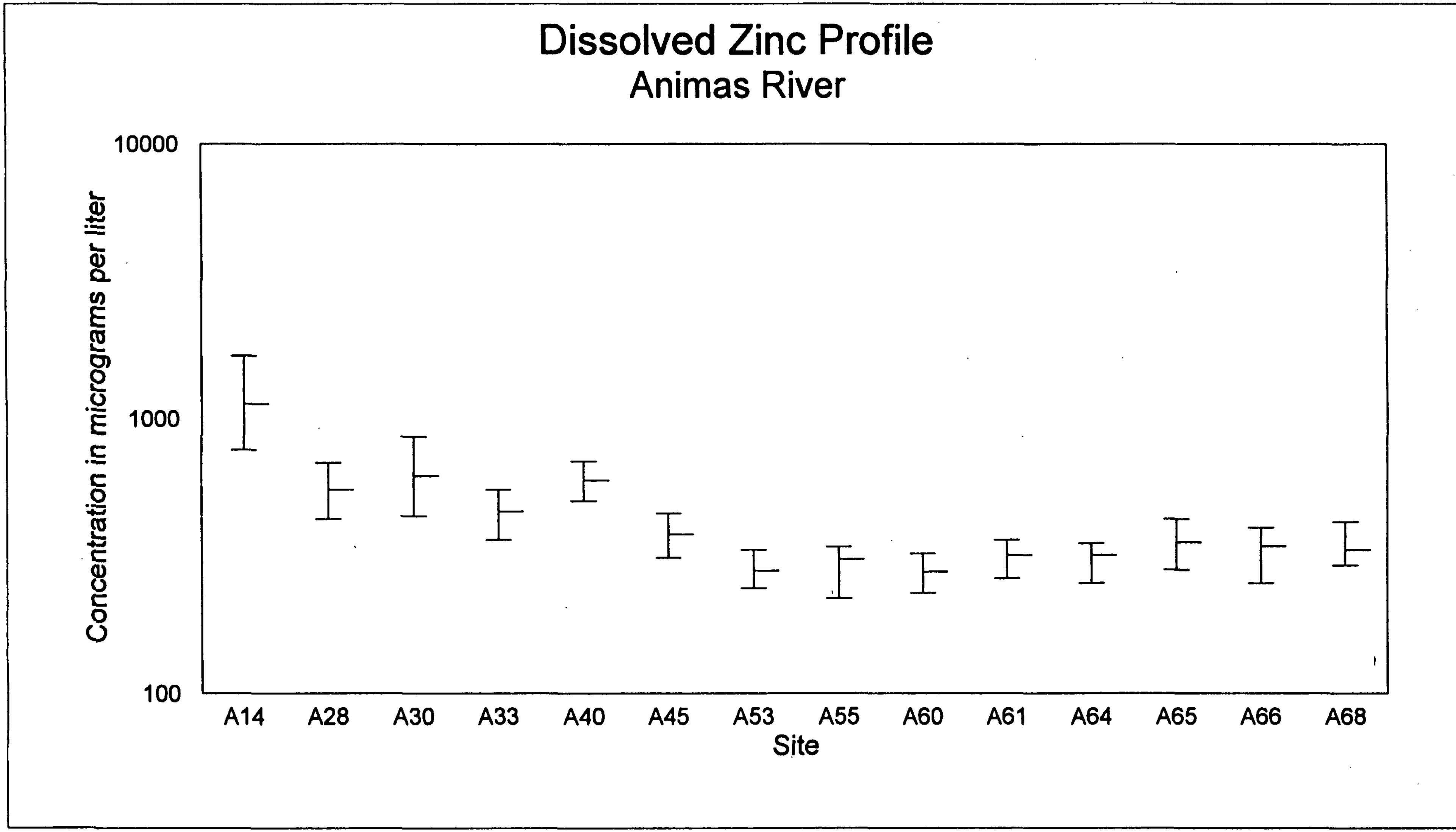
Dissolved Zinc Profile
Animas River
10000
1000
100
Concentration in micrograms per liter
A14
A28
A30
A33
A40
A45
A53
A55
A60
A61
A64
A65
A66
A68
Site

Figure 7

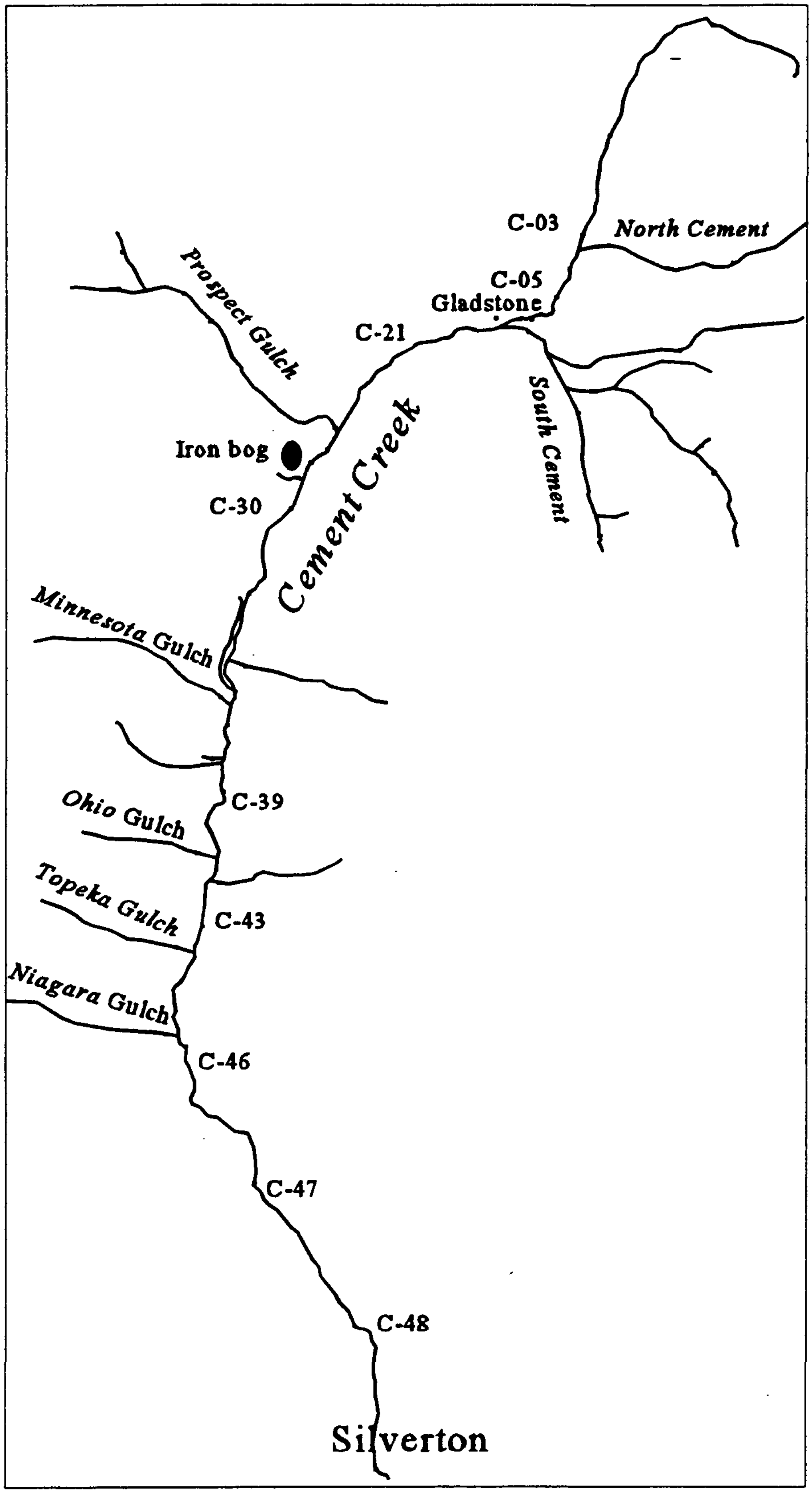


Figure 8 Selected Sampling Locations, Cement Creek